MANUFACTURE OF A DEVICE FOR PRUNING FRUIT BRANCHES
/
تصنيع جهاز لتقليم الأفرع الثمرية

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ABSTRACT
Fruit branch pruning is still done manually, resulting in high labor costs, ergonomic hazards, and low efficiency and productivity. Furthermore, there are some limitations with imported agricultural machines because of their high prices and inappropriate local conditions. Hence, the present study aims to manufacture a local device for fruit branch pruning based on validating the correct stem-cutting position using a branch guide. The manufactured device comprises a 60 W electric motor, a formed base, a teethed pruning disc, a telescopic tube made up of the picker-cutting mechanism of the device, and a 12–Volt rechargeable dry battery. The device was made from local and light materials to allow a telescopic tube to reach the high position of the citrus fruit branches and consider ergonomic aspects. Field trials were executed on sour oranges trees to assess the pruning device's performance as a function of change in peripheral speeds of cutting disc (9.81, 13.74, 17.66, and 21.59 m/s), cutting disc teeth numbers (60, 80, and 100 teeth), different groups of branches diameters {A (from 5 mm to less than 10 mm), B (10 mm to less than 20 mm), C (from 20 mm to less than 30 mm) and D (from 30 mm to less than 40 mm)}. The manufactured device was assessed in terms of device productivity, pruning efficiency, pruning damage, power requirements, specific energy, and operating cost. The results indicated that the highest device productivity and pruning efficiency were 780, 218, 100 and 65 branch/h; and 96.0, 94.0, 92.0 and 90.5%, while the lowest pruning branch damage were 4.0, 6.0, 8.0 and 9.5%, specific energy were 0.0447, 0.1645, 0.4050 and 0.700 Wh per branch, for the groups of branches diameters A, B, C, and D respectively. The current investigation recommended that the optimal operational conditions were using the manufactured device for pruning citrus trees at 17.66 m/s pruning disc speed with a pruning disc teeth number of 60 teeth.

الملخص
لا يزال تقليم أغصان الفاكهة يتم بالصورة اليدوية، والذي ينتج عنه ارتفاع تكاليف العمالة والمخاطر الجسدية للعامل وانخفاض كفاءة وانتاجية العامل لعملية التقليم. علاوة على ذلك، هناك بعض القيود بالنسبة لاستيراد الآلات الزراعية بسبب ارتفاع أسعارها وعدم ملاءمتها للظروف المحلية. ومن ثم، تهدف الدراسة الحالية إلى تصنيع جهاز محلي لتقليم أغصان الفاكهة حيث يعتمد في تصميمه على التحقق من صحة موضع قطع الساق الصحيح باستخدام دليل الفرع. ويتكون الجهاز من موتور كهربي بقدرة 60 وات، وقاعدة مشكلة، وقرص تقليم مسنن وأنبوب تلسكوبي وبطارية جافة 12 فولت. تم تصنيع الجهاز من خامات محلية وخفيفة الوزن للسماح لأنبوب تلسكوبي بالوصول إلى الموضع المرتفع لأغصان الشجرة وأيضا لمراعاة بيئة عمل مريحة للعامل. وأجريت التجارب على أشجار النارنج لتقييم أداء جهاز التقليم عند استخدام أربع سرعات محيطية لقرص القطع (9.81، 13.74، 17.66 و21.59 م/ث)، عدد أسنان قرص القطع (60، 80، 100 سن)، أربع مجموعات مختلفة لأقطار الفروع {A (من 5 مم إلى أقل من 10 مم)، B (10مم إلى أقل من 20 مم)، C (من 20 مم إلى أقل من 30 مم) و D (من 30 مم إلى أقل من 40 مم)}. وتم تقييم أداء الجهاز المصنع من حيث إنتاجية الجهاز وكفاءة التقليم ونسبة تلف الناتج عن التقليم ومتطلبات القدرة والطاقة والتكلفة التشغيلية. وأظهرت النتائج أن أعلى قيم إنتاجية للجهاز وكفاءة التقليم كانت 780 و218 و100 و65 فرعًا في الساعة؛ و96.0 و94.0 و92.0 و90.5٪ بينما كانت أقل قيم تلف فرع التقليم 4.0 و6.0 و8.0 و9.5٪ ومتطلبات الطاقة 0.0447 و0.1645 و0.4050 و0.700 وات ساعة لكل فرع لمجموعات الفروع بأقطار A و B و C و D على التوالي. وأوصت الدراسة الحالية بان ظروف التشغيل المثلى هي باستخدام جهاز التقليم المصنع عند سرعة تقليم 17.66 م/ث مع قرص القطع بعدد أسنان 60 سن لتقليم أشجار الحمضيات.

INTRODUCTION
Fruit and citrus trees are a major source of income for the country. Fruit trees are extremely important in the production of food. Egypt's total cultivated fruit trees area was 420,000 ha, 150,000 ha of which are citrus (about 12,300 million trees).

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The most important citrus cultivars are sweet orange (approximately 65%), followed by local mandarin (25%) and lemon (10%). The average production ranges between 15–17 tons/ha, with total citrus production of 3,240,000 tons in 2020 (*MALR, 2020*). Pruning is a crucial canopy managing strategy for achieving and sustaining optimal yield with profitable fruit size plus quality (*Krajewski et al., 2021*). Pruning methods in citriculture are crucial in keeping plant health to achieve a satisfactory symmetry between reproductive and vegetative growth, which is an essential aspect of citrus crop development (*Intrigliolo and Roccuzzo, 2011*). Pruning eliminates ineffective and/or damaged branches, diminishes excess fruit on the tree, plus improves nutrient distribution, thus resulting in larger fruits. Generally, the tree's response to pruning relies on many aspects, including tree variety, tree age, rootstock, growing circumstances, production practices, and pruning time during the growing period (*Kadlec et al., 2022; Vashisth et al., 2022*).

Furthermore, pruning can lessen competition for assimilates, thereby maximizing assimilate distribution, and it is an eco-friendly aspect of diminishing crop load (*Bound, 2021*). Pruning is the second greatest labor expense after harvesting expenses in tree fruit production, representing approximately 20% or over of the entire pre-harvest production cost (*Gallardo et al. 2009; Hansen 2011*). Also, Chueca et al. (2021) and Martin-Gorriz et al. (2021) reported that pruning is the second most costly mission in citrus production after harvesting. General, manual pruning costs account for between 10% and 15% of entire citrus production costs and 30% to 50% of entire labor costs. In a similar vein, Fonte *et al.* (2022) stated that pruning is regarded as one of the most costly and laborious tasks of citrus production, and its mechanization could boost citrus farms' efficiency and competitiveness. The influence of mechanical pruning on yield relies on the variety, location, and crop condition, among further aspects. Pruning can be done manually or mechanically, utilizing pruning tools (*Abbood et al., 2019*). Manual citrus pruning is performed mostly with hand scissors and saws. This practice has disadvantages and causes considerable problems, including but not limited to being slow, costly, and requires skilled laborers that know how to prune appropriately (*Intrigliolo and Roccuzzo, 2011; Liu et al., 2018; Zhang et al.,2020)*. On the other side, mechanical pruning chiefly uses a machine to prune and shape on a vast scale and in orchards with standardized planting arrangements (*Chueca et al., 2021*). Common fruit tree pruning machines consist of a pruning device, a power system, a frame, and additional key parts (*Ottanelli et al., 2019*). Mechanical pruning primarily involves hedging, and only some pruning machines, such as teeth-type and disc-type cutters, are available for tree fruit harvests, depending upon the requirements. Mechanical pruning could be implemented by hedging on both sides of the canopy and/or topping the canopy parallel to the ground (*Dias et al., 2014*). Rubin *et al*. (2019) designed and manufactured a tree-pruning device. The device comprises a rectangular frame of mild steel that supports all the parts to be built upon. It has four wooden rollers with rubber grippers and two drilling machine motors. A stationary blade made of stainless steel is mounted on the frame. The motors are electrically supplied, and a relay controller comprises a remotely operable electromagnetic switch that regulates their motion. The device is equipped with a spring-loaded mechanism to provide flexibility during climbing the tree. The device has been evaluated and proven safe, dependable, and effective. Therefore, it minimizes the difficulty of climbing trees and cutting branches.

As the cultivation of fruit trees grew, it was imperative to develop pruning methods for completing the pruning process quickly, easily, and with high quality so as not to break the fruit branches or scratch the fruits, causing them to rot. Therefore, the present study aims to manufacture a device with a branch guide for fruit branch pruning and determine the best operating parameters for the fruit pruning device.

MATERIALS AND METHODS

The manufactured tree-pruning device

The pruning device was manufactured at a private workshop in Sharkia Governorate, Egypt. The manufactured citrus tree pruning device comprises three main parts (i.e., telescopic tubes, pruning unit, and battery), as shown in Fig. 1. The pruning device was made from light materials to allow a telescopic tube to reach the high positions on the tree, in addition to ergonomic considerations. The manufactured device was based on validating the correct stem-cutting position, safeguarding the branch from harm. The first part comprises six telescopic tubes made of plastic with a thickness of 1 mm were used to carry the pruning unit on its top. Each tube has a length of 500 mm and edges diameters of 36 and 32 mm. Second, the pruning unit comprises a teethed pruning disc, a power source, a formed base, a pruning disc house, and a branch guide.

The teethed pruning disc was made of alloy steel with 1 mm thickness and 125 mm diameter. Three teethed pruning discs with teeth numbers 60, 80, and 100 were tested, as shown in Fig. 2. A 60-watt electric motor was used to operate the pruning unit.

The motor specifications are Buhler Motor GmbH Germany, brushed type, voltage 12, torque 0.18 Nm, power 60 W (0.082 HP), rotational speed 3,300 rpm, and 39 mm shaft diameter. The motor shaft interfered with a threaded plate of 18 mm diameter and 6.5 mm thickness. The pruning disc was connected with a threaded plate by a nut with an inside diameter of 18 mm. There is a formed base underneath the threaded plate. This base was bolted with the motor by three bolts of 3 mm diameter. The base has a U-shaped guide, and its other side has a bent bracket bolted with the telescopic tube. The pruning disc housing consists of two plastic covers with a 156 mm diameter, 17 mm height, and 1.5 mm thickness. Each cover was bolted with the formed base by bolts with a diameter of 3 mm. The branch guide is located on the U-shaped formed base. The distance between the sides is 50 mm, and its length is 60 mm until the beginning of the pruning disc with a width of 15 mm. The branch guide was used to control the branches during the pruning process.

The pruning-device base was fastened with the top of the telescopic tube by two iron brackets with 1.5 mm thickness, 100 mm length, and 25 mm width. The two brackets were bolted with the end of the telescopic tube by two bolts with a 5 mm diameter. The total mass of the pruning device with telescoping tubes is 1400 g. Third, a 12-Volt rechargeable dry battery is connected by an electric cable with a 2 mm thickness. Each telescopic tube has an electric cable passed through, and the operator carries the battery bag by belt. The total mass of the bag with the battery is 3180 g. An adjustable voltage regulator was used to allow the operator to control and adjust the electric motor's rotational speed by altering the voltage's control switch to achieve the required speeds.

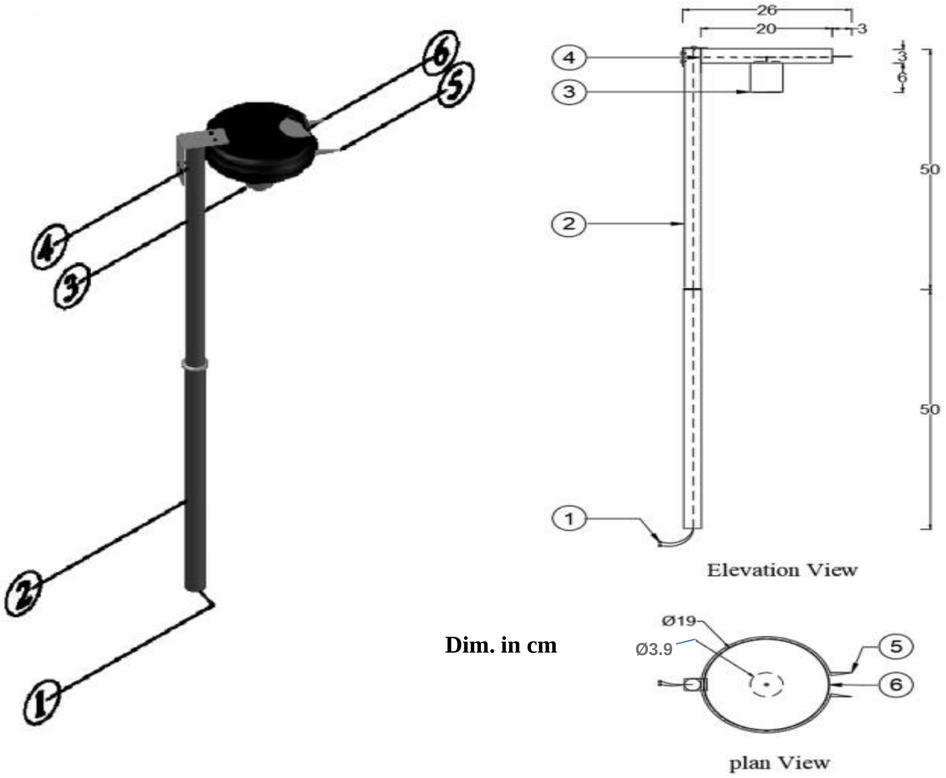

Fig. 1 – Views of the manufactured pruning device for citrus trees

1 – Electrical cable; 2 – Telescopic tube; 3 – DC-motor; 4 – Disc housing; 5 – Branch guide; 6 – Pruning disc

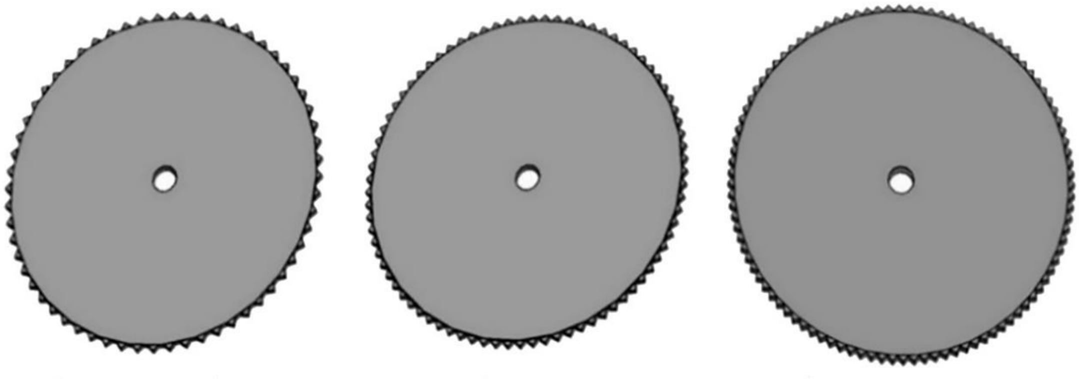

Fig. 2 – Three different numbers of pruning disc teeth

The citrus trees

Citrus orange trees (sour orange) were selected to evaluate the manufactured pruning device's performance because its branches contain thistle, which is difficult to perform manually, as shown in Fig. 3.

Fig. 3 – Image of the pruning device during pruning citrus trees

Parameters and measurements

The manufactured pruning device was evaluated under four different peripheral speeds of pruning disc (9.81, 13.74, 17.66, and 21.59 m/s), three different numbers of pruning disc teeth (60, 80, and 100 teeth), four groups of the sour orange trees branches diameters "A – B – C – D" (i.e., "A" branches with diameters from 5 mm to less than 10 mm, "B" branches with diameters from 10 mm to less than 20 mm, "C" branches with diameters from 20 mm to less than 30 mm, and "D" branches with diameters from 30 mm to less than 40 mm. The manufactured device was assessed for its performance in terms of pruning productivity, efficiency, damage, power requirements, specific energy, and operational cost.

The pruning device productivity was determined in terms of the number of pruned branches per hour. The pruning device productivity was determined according to Eq. (1) as follows:

$$PDP = \frac{Q}{t} \tag{1}$$

where PDP is the pruning device productivity [branch/h], Q is the number of pruned branches after pruning [branch], and t is the time required for pruning branches of the citrus trees [h].

The pruning efficiency was determined according to Eq. (2) as follows:

$$PE = \frac{Q}{M_{mb}} \times 100 \tag{2}$$

where PE is the pruning efficiency [%], Q is the number of pruned branches after pruning [branch], and M_{mb} is the number of mature branches needed for pruning on the tree before pruning [branch].

The pruning branches damage was calculated according to Eq. (3) as follows:

$$PBD = \frac{M_{da}}{M_{mb}} \times 100 \tag{3}$$

where PBD is the pruning branches damage [%], M_{da} is the number of damaged branches after pruning [branch], and M_{mb} is the number of mature branches needed for pruning on the tree before pruning [branch].

The power requirements for the pruning device in this study were calculated according to Eq. (4) as follows:

$$PR = \frac{I \times V \times cos\theta}{1000} \tag{4}$$

where PR is the power requirements [kW], I is the line current strength [Amperes], V is the potential difference [Voltage], and $cos\theta$ is the power factor ≈ 0.85.

The specific energy for the pruning device was determined according to Eq. (5) as follows:

$$SE = \frac{PR}{PDP} \tag{5}$$

where SE is the specific energy [kWh/branch], PR is the power requirements [kW], and PDP is the pruning device productivity [branch/h].

The pruning device hourly cost was estimated according to (*Awady et al., 1978),* as follows in Eq. (6):

$$C = \frac{p}{h}\left(\frac{1}{l} + \frac{i}{2} + t + r\right) + (PR \times e) + \left(\frac{m}{144}\right) \tag{6}$$

where C is the pruning device hourly cost [EGP/h], p is the pruning device price [EGP], h is the pruning device yearly operating hours [h/year], l is the pruning device life expectancy [h], i is the interest rate per year [%], t is the taxes rate [%], r is the repair and maintenance ratio [%], PR is the power requirements [kW], e is the hourly electricity cost [EGP/kWh], m is the operator's monthly wage [EGP], and 144 is the monthly working hours.

The operational cost per branch was estimated according to Eq. (7) as follows:

$$OCPB = \frac{C}{PDP} \tag{7}$$

where $OCPB$ is the operational cost per branch [EGP/branch], C is the pruning device hourly cost [EGP/h], and PDP is the pruning device productivity [branch/h].

The operational cost per tree was estimated according to Eq. (8) as follows:

$$OCPT = OCPB \times NBPT \tag{8}$$

where $OCPT$ is the operational cost per tree [EGP/tree], $OCPB$ is the operational cost per branch [EGP/branch], $NBPT$ is the number of branches per tree [branch/tree].

RESULTS AND DISCUSSION

Influence of operating parameters on the manufactured device productivity

Fig. 4 presents the influence of the peripheral speed of the pruning disc, pruning disc teeth number and branches diameter on the device productivity. Concerning the influence of the peripheral speed of the pruning disc on the manufactured device productivity, the results reveal that increasing the peripheral speed of the pruning disc increased the device productivity at any pruning disc teeth number and branch diameter. The obtained results indicate that increasing the peripheral speed of the pruning disc from 9.81 to 21.59 m/s at a constant pruning disc teeth number of 60 teeth increased device productivity from 530 to 850, from 165 to 260, from 64 to 120, and from 40 to 88 branch/h, under sour orange branches diameters A, B, C, and D, respectively. This may be because increasing the peripheral speed of the pruning disc decreases the required cutting force, accelerating the pruning period and thus increasing productivity. These results are in line with *Abdallah et al. (2014)* and *Moradpour et al. (2016)*.

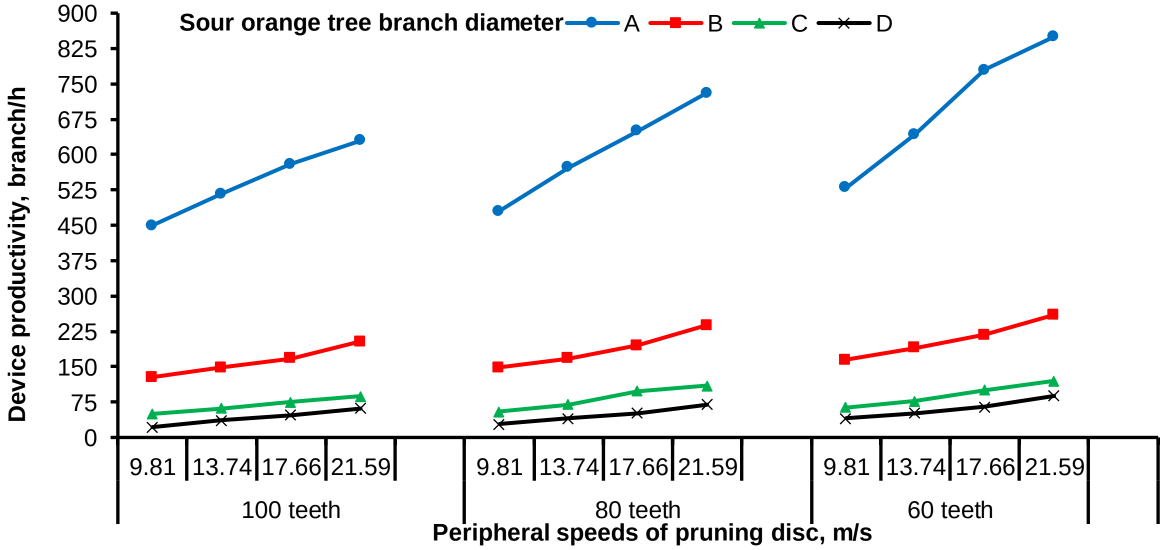

Fig. 4 – Influence of operating parameters on the manufactured pruning device productivity

Regarding the influence of the pruning disc teeth number on the device productivity, the results show that decreasing pruning disc teeth number increased device productivity at any peripheral speed of the pruning disc and branch diameter. The obtained results reveal that decreasing the pruning disc teeth number from 100 to 60 teeth at a constant peripheral speed of the pruning disc of 21.59 m/s increased device productivity from 630 to 850, from 203 to 260, from 87 to 120, and from 62 to 88 branch/h, under sour orange branches diameters A, B, C, and D, respectively.

Relating the influence of branch diameter on the device productivity, the results demonstrate that increasing branch diameter decreased the device productivity at any peripheral speed of the pruning disc and pruning disc teeth number. The obtained results show that increasing branch diameter from A to D at a constant peripheral speed of the pruning disc of 21.59 m/s decreased the device productivity by a percentage of 89.65, 90.42, and 90.16% at pruning disc teeth number 60, 80, and 100 teeth, respectively. This may be ascribed to the fact that increasing branch diameter caused an increase in branch resistance for cutting, which increases the required time for pruning, hence decreasing productivity. These results are in agreement with *Esgici et al. (2019), Kang et al. (2020)*, and *Li et al. (2022)*.

Regarding the influence of the pruning disc teeth number on the device productivity, the results show that decreasing pruning disc teeth number increased device productivity at any peripheral speed of the pruning disc and branch diameter. The obtained results reveal that decreasing the pruning disc teeth number from 100 to 60 teeth at a constant peripheral speed of the pruning disc of 21.59 m/s increased device productivity from 630 to 850, from 203 to 260, from 87 to 120, and from 62 to 88 branch/h, under sour orange branches diameters A, B, C, and D, respectively.

Relating the influence of branch diameter on the device productivity, the results demonstrate that increasing branch diameter decreased the device productivity at any peripheral speed of the pruning disc and pruning disc teeth number. The obtained results show that increasing branch diameter from A to D at a constant peripheral speed of the pruning disc of 21.59 m/s decreased the device productivity by a percentage of 89.65, 90.42, and 90.16% at pruning disc teeth number 60, 80, and 100 teeth, respectively. This may be ascribed to the fact that increasing branch diameter caused an increase in branch resistance for cutting, which increases the required time for pruning, hence decreasing productivity. These results are in agreement with *Esgici et al. (2019), Kang et al. (2020),* and *Li et al. (2022)*.

Influence of operating parameters on pruning efficiency

Fig. 5 illustrates the effect of the peripheral speed of the pruning disc, pruning disc teeth number and branch diameter on pruning efficiency. Regarding the effect of the peripheral speed of the pruning disc on pruning efficiency, the results declare that increasing the peripheral speed of the pruning disc up to 17.66 m/s increased the pruning efficiency at any pruning disc teeth number and branch diameter. Furthermore, increasing the peripheral speed of the pruning disc from 17.66 to 21.59 m/s tends to decrease the pruning efficiency. The attained results reveal that increasing the peripheral speed of the pruning disc from 9.81m/s to 17.66 m/s at a constant pruning disc teeth number of 60 teeth increased pruning efficiency from 93.0 to 96.0%, from 90.0 to 94.0%, from 87.0 to 92.0%, and from 85.0 to 90.5%, under sour orange branches diameters A, B, C, and D, respectively. This may be due to the increased impact forces applied to the branch, which improve pruning operation and hence pruning efficiency.

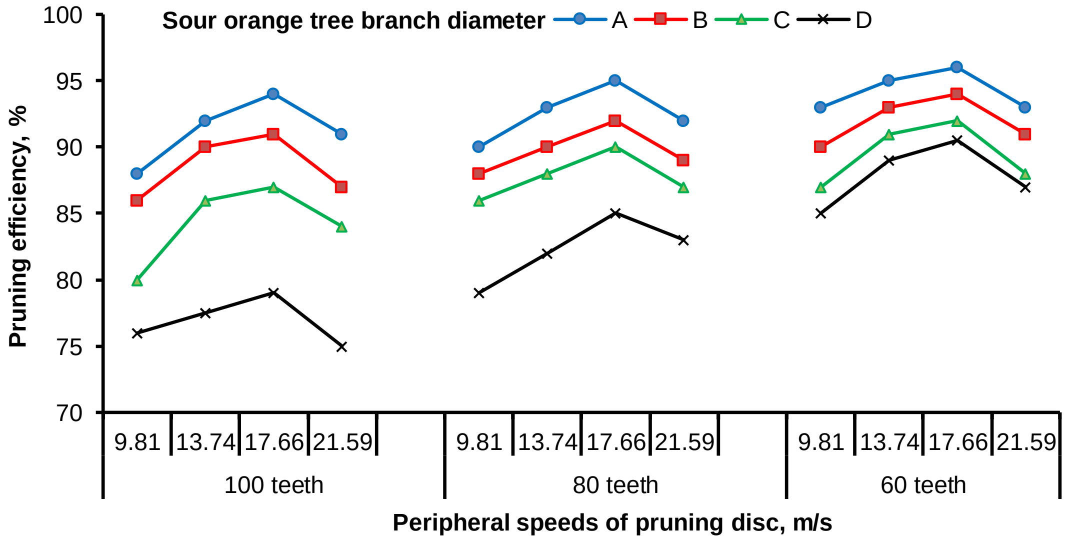

Fig. 5 – Influence of operating parameters on pruning efficiency

Concerning the influence of pruning disc teeth number on pruning efficiency, the results show that decreasing pruning disc teeth number from 100 to 60 teeth at a constant peripheral speed of the pruning disc of 17.66 m/s increased the pruning efficiency from 94.0 to 96.0%, from 91.0 to 94.0%, from 87.0 to 92.0%, and from 79.0 to 90.5%, under branches diameters A, B, C, and D, respectively.

Regarding the impact of branch diameter on pruning efficiency, the results illustrate that increasing the branch diameter decreased pruning efficiency at any peripheral speed of the pruning disc and pruning disc teeth number, as shown in Fig. 5, where increasing branch diameter from A to D at a constant peripheral speed of the pruning disc of 17.66 m/s decreased the pruning efficiency by a percentage of 5.73%, 10.53%, and 15.95%, at pruning disc teeth number of 60, 80, and 100 teeth, respectively. This may be attributed to the increase in branch diameter, causing an increase in branch resistance for cutting, which increases the required cutting force for pruning, accordingly decreasing pruning's efficiency. These results are in line with *Li et al. (2022).*

Influence of operating parameters on the pruning branch damage

The pruning branch damage is greatly affected by the peripheral speed of the pruning disc, pruning disc teeth number and branch diameter, as shown in Fig. 6. Regarding the effect of the peripheral speed of the pruning disc on the pruning branch damage, increasing peripheral speed of the pruning disc from 9.81 to 17.66 m/s at a constant pruning disc teeth number of 60 teeth decreased pruning branch damage from 7.0 to 4.0%, from 10.0 to 6.0%, from 13.0 to 8.0%, and from 15.0 to 9.5%, under sour orange branches diameters A, B, C, and D, respectively. This may be due to increasing the peripheral speed of the pruning disc accelerating the pruning process; thus, fewer times are required to use the pruning disc to prune one branch, consequently decreasing the pruning damage. Any increase in the peripheral speed of the pruning disc of over 17.66 m/s up to 21.59 m/s increased the pruning branch damage from 4.0 to 7.0%, from 6.0 to 8.0%, from 8.0 to 12.0%, and from 9.5 to 13.0% under the same previous conditions.

Fig. 6 presents the influence of the pruning disc teeth number on the pruning damage. The results demonstrate that increasing the pruning disc teeth number from 60 to 100 teeth at a constant peripheral speed of the pruning disc of 17.66 m/s, increased the pruning damage from 4.0 to 6.0%, from 6.0 to 8.0%, from 8.0 to 13.0%, and from 9.5 to 21.0% under branches diameters A, B, C, and D, respectively.

Concerning the influence of branch diameter on pruning damage percentage, it was clear that increasing branch diameter from A to D at a constant peripheral speed of the pruning disc of 17.66 m/s increased pruning damage percentage by a percentage of 57.89, 66.66, and 71.43%, at pruning disc teeth number of 60, 80, and 100 teeth, respectively. This may be because the increase in the branch's diameter led to increased resistance of the branches to pruning, which in turn required several times the use of the pruning disc to prune one branch, thus increasing the pruning damage.

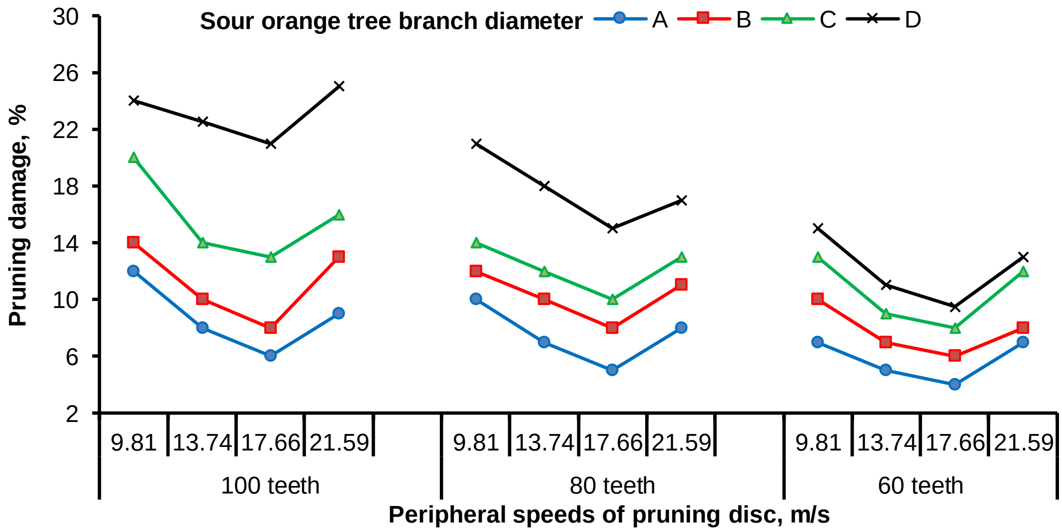

Fig. 6 – Influence of operating parameters on the pruning branch damage

Influence of operating parameters on the power requirements and specific energy

Figs. 7 and 8 show the influence of the peripheral speed of the pruning disc, pruning disc teeth number and branch diameter on power requirements and specific energy. Concerning the influence of the peripheral speed of the pruning disc on power requirements and specific energy, the results illustrate that increasing peripheral speed of the pruning disc from 9.81 m/s to 21.59 m/s at a constant pruning disc teeth number of 60 teeth increased power requirements from 29.55 W to 36.33 W, from 30.72 W to 39.50 W, from 35.45 W to 43.35 W, and from 40.33 to 48.10 W, under branches diameters A, B, C, and D, respectively.

These results are in harmony with *Hegazy et al. (2021).* In contrast, the specific energy decreased by a percentage of 22.46, 18.42, 34.80, and 45.79% under the same conditions. These results are in line with *Awad et al. (2022).*

Regarding the effect of pruning disc teeth number on power requirements and specific energy, the results reveal that increasing pruning disc teeth number from 60 to 100 teeth at a constant peripheral speed of the pruning disc of 21.59 m/s increased power requirements from 36.33 W to 39.35 W, from 39.50 W to 42.78 W, from 43.35W to 50.25 W, and from 48.10 W to 58.62 W, under branches diameters A, B, C, and D respectively. In the same vein, the specific energy increased by a percentage of 31.41%, 27.91%, 37.46%, and 42.19% under the same conditions.

Relating the influence of branch diameter on power requirements and specific energy, it was clear that increasing branch diameter from A to D at a constant peripheral speed of the pruning disc of 21.59 m/s increased power requirements from 36.33 W to 48.10 W, from 38.22 W to 55.35 W, and from 39.35 to 58.62 W, at pruning disc teeth number of 60, 80, and 100 teeth, respectively. This may be attributed to the increasing branch diameter, increasing the branch resistance for pruning, hence increasing the required power. These results are in agreement with *Li et al. (2022).* In the same vein, the specific energy increased by a percentage of 92.17%, 93.38%, and 93.40% under the same conditions.

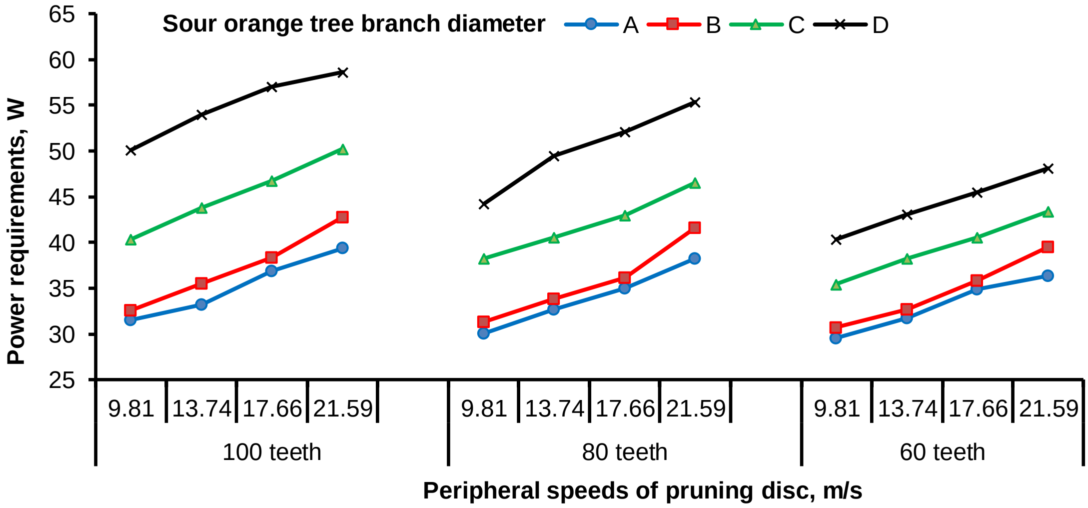

Fig. 7 – Influence of operating parameters on the power requirements

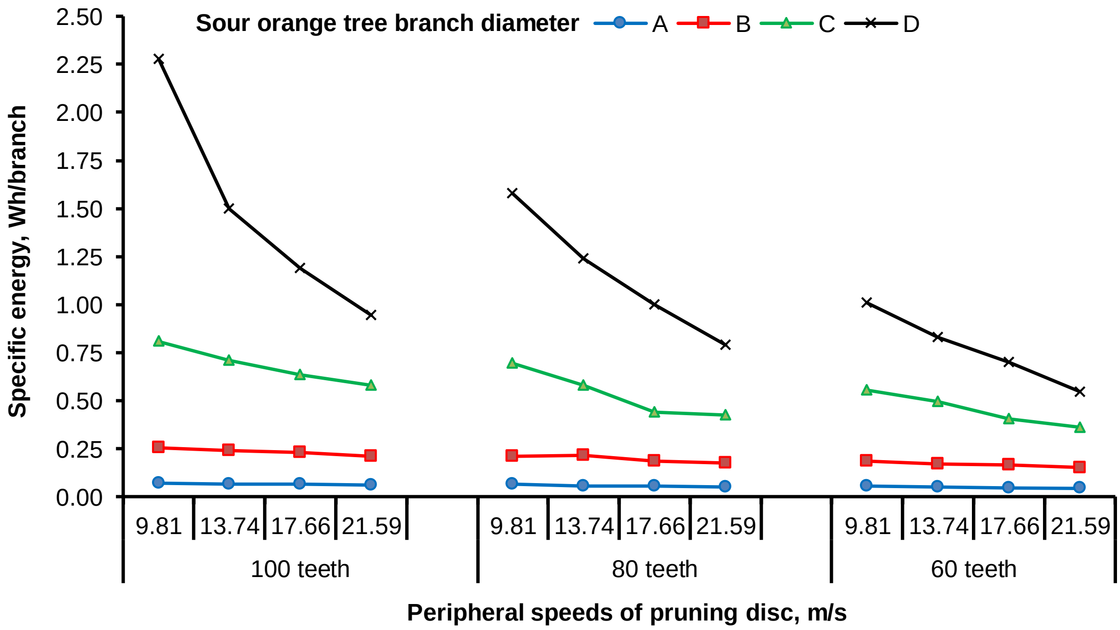

Fig. 8 – Influence of operating parameters on specific energy

Influence of operating parameters on operational costs

A cost analysis was performed for the manufactured device under different operating conditions related to the productivity of the pruning device. The total manufacturing cost of the device was 2000 EGP, according to the 2022 prices. The device's life expectancy is five years.

The results demonstrate that the operational cost per tree was affected by the peripheral speed of the pruning disc, pruning disc teeth number, and power. Fig. 9 presents the representative values of operational cost per tree versus peripheral speed of the pruning disc and pruning disc teeth number for the different groups of sour orange branch diameters.

Concerning the effect of pruning disc teeth number on the operational cost, the results show that increasing the number of disc teeth at any peripheral speed of the pruning disc increased the operational cost. With the increasing pruning disc teeth number from 60 to 100, at a constant peripheral speed of the pruning disc of 17.66 m/s, the operating cost increased from 4.07 to 5.45 EGP/tree. The increase in operational cost of pruning disc teeth is attributed to the decrease in device productivity with discs with higher teeth numbers.

Relating the effect of the peripheral speed of the pruning disc on the operational cost, the results show that increasing the peripheral speed of the pruning disc decreased the operational cost at any pruning disc teeth number. Increasing the peripheral speed of the pruning disc from 9.81 to 21.59 m/s decreased the operational cost from 6.2 to 3.9 EGP/tree. The decrease in operational cost by increasing the peripheral speed of the pruning disc is attributed to the increase in device productivity accompanied by the high disc speed.

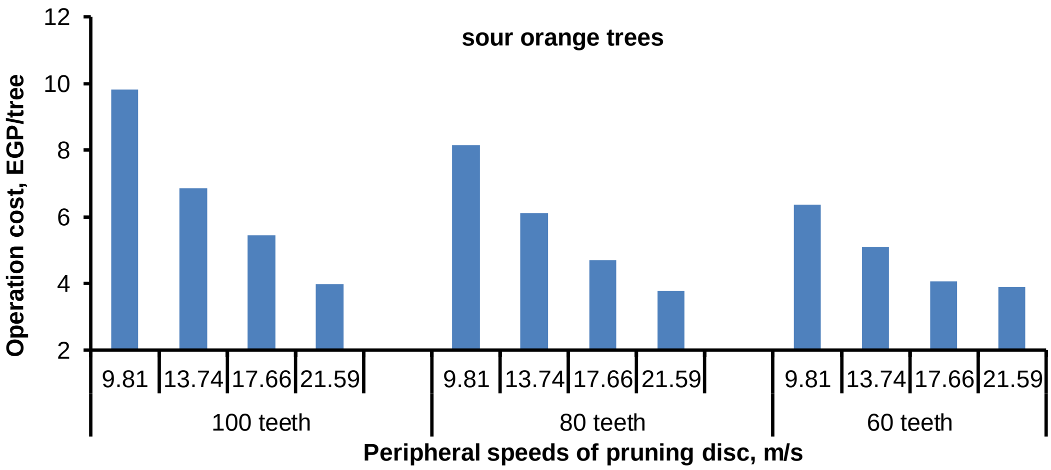

Fig. 9 – Effect of operating parameters on operational costs

CONCLUSIONS

The findings in the current research confirmed the effectiveness of using the manufactured pruning device for pruning citrus trees. Therefore, using the manufactured pruning device for pruning citrus trees under 17.66 m/s peripheral speed of the pruning disc with a pruning disc of 60 teeth can be recommended. Under these conditions, the following data were achieved, the highest values of pruning device productivity and pruning efficiency were 780, 218, 100, and 65 branch/h; and 96.0, 94, 92, and 90.5% for the groups of sour orange branches diameters A, B, C, and D respectively. The lowest values of pruning damage were 4.0, 6.0, 8.0, and 9.5%, and energy requirements were 0.0447,0.1645, 0.4050, and 0.700 Wh/branch for the groups of sour orange branches diameters A, B, C, and D respectively. The operational costs were 4.07, 4.70, and 5.45 EGP/tree when using pruning discs 60, 80, and 100 teeth at a constant peripheral speed of the pruning disc of 17.66 m/s for the sour orange trees, respectively.

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